

R&D for Net-Zero Energy High-Performance Green Buildings

Patrick Hughes, Director
**Building Technologies Research
& Integration Center**
for

**NASA 2011 Facilities Engineering &
Real Property Conference**
Hilton Nashville Downtown

May 10, 2011

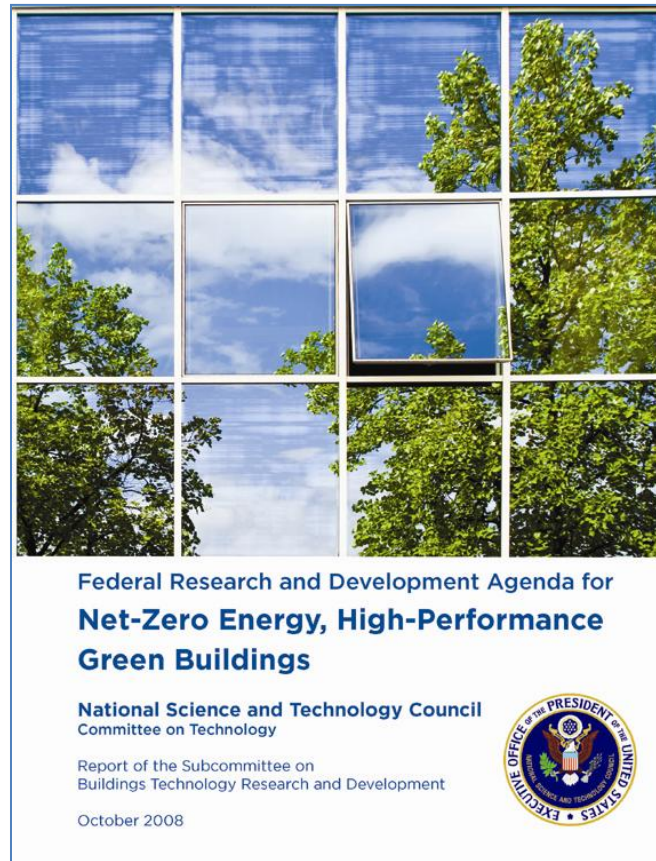


Energy is the defining challenge of our time — buildings play a big part

**Global energy consumption
will increase 50% by 2030**

- **Consumption of buildings in U.S.**
 - 40% of primary energy/carbon, 73% of electricity, 34% of natural gas
- **Buildings in China**
 - 60% of the buildings in Chinese cities in 2030 will have been constructed since 2006
 - In 2015 half the world's building construction will be occurring in China
- **Buildings in India**
 - 80% of the buildings in India in 2030 will have been constructed since 2006
- **Incremental changes to practices and technologies cannot meet this challenge**

Federal R&D Agenda for Net-Zero Energy High-Performance Green Buildings



Report can be downloaded at
<http://www.whitehouse.gov/administration/eop/ostp/nstc/docsreports/archives>
under 2008

National Science and Technology Council Planning Framework

The National Science and Technology Council (NSTC) was established on November 23, 1993. This Cabinet-level council is the principal means within the executive branch to coordinate science and technology policy across the diverse entities that make up the Federal research and development enterprise.

Chaired by the President, the NSTC is made up of the Vice President, the Director of the Office of Science and Technology Policy, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other White House officials.

COMMITTEE ON TECHNOLOGY

AERONAUTICS

BIOMETRICS & IDENTITY MANAGEMENT

BUILDINGS TECHNOLOGY RESEARCH & DEVELOPMENT

HYDROGEN & FUEL CELLS

INNOVATION & COMPETITIVENESS

MANUFACTURING RESEARCH & DEVELOPMENT

NANOSCALE SCIENCE, ENGINEERING & TECHNOLOGY

NETWORKING & INFORMATION TECHNOLOGY

QUANTUM INFORMATION SCIENCE

Buildings Technology R&D (BTRD) Subcommittee

Shyam Sunder, Co-Chair (Director EL/NIST/DOC)

Roland Risser, Co-Chair (Building Technologies/EE&RE/DOE)

Assess Federal support for and policies relevant to building technology; identify R&D priorities and opportunities; develop long-range, interagency R&D plans

Provide R&D guidance aimed at supporting advances in buildings technology and related infrastructure, with a particular focus on enabling the energy-efficient, automated operation of buildings and building systems

Provide R&D guidance to enable sustainable renewal of the nation's physical infrastructure, improve construction productivity, enhance disaster resilience of buildings, and benefit human health and productivity

16 U.S. Government Agencies, the Architect of the Capitol, U.S. Postal Service, and the Smithsonian Institution

Buildings Technology R&D (BTRD) Subcommittee

U.S. Department of Agriculture

U.S. Department of Commerce (co-chair)

U.S. Department of Defense

U.S. Department of Energy (co-chair)

**U.S. Department of Health and Human
Services**

U.S. Department of Homeland Security

**U.S. Department of Housing and Urban
Development**

U.S. Department of the Interior

U.S. Department of Labor

U.S. Department of State

U.S. Department of Veterans Affairs

U.S. Environmental Protection Agency

U.S. General Services Administration

**National Aeronautics and Space
Administration**

National Science Foundation

Executive Office of the President

Office of the Architect of the Capital

Smithsonian Institution

U.S. Postal Service

Federal R&D Agenda Has Six Goals

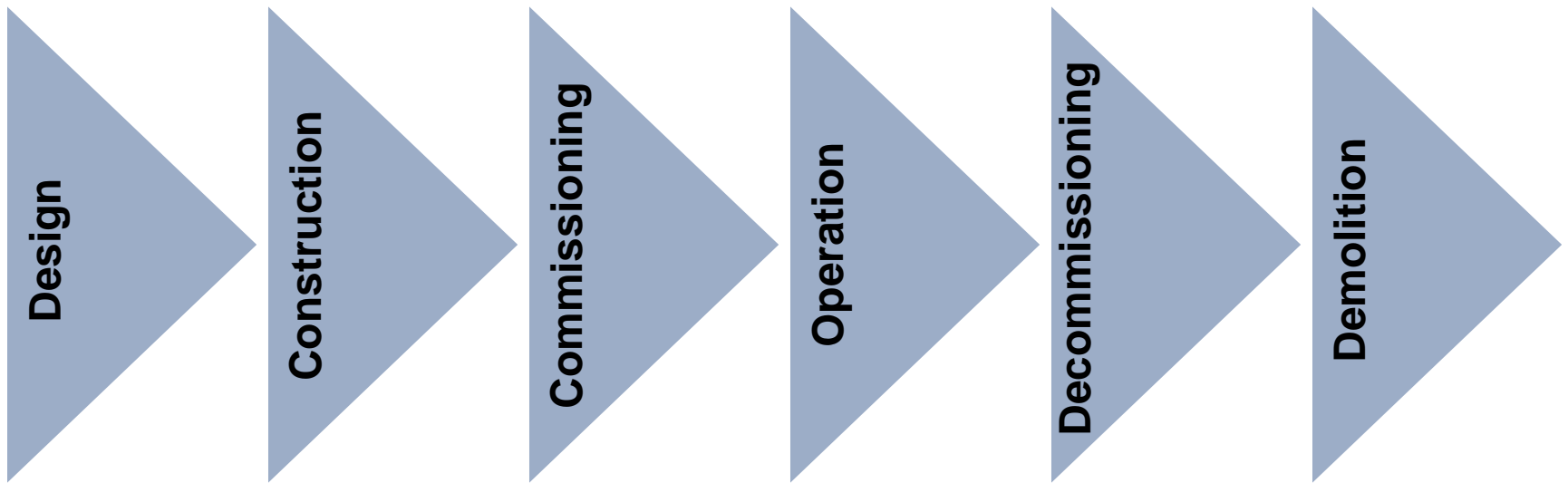
- **Integrated, Performance-Based Design and Operation**
- **Net-Zero Energy Building Technologies and Strategies**
- **Water Use and Rainwater Retention**
- **Material Utilization, Waste, and Life Cycle**
- **Environmental Impacts, Occupant Health and Performance**
- **Overcoming Barriers to Implementation**

Integrated, Performance-Based Design and Operation

Goal 1: Develop the enabling measurement science to achieve net-zero energy, high-performance green building technologies

Focus Area a. Develop rigorous metrics

Focus Area b. Enable widespread adoption of high-performance goals by developing practical tools and processes to address the complex interactions of building components and systems throughout the building life cycle



Manage buildings throughout their life cycle as a single integrated asset using building information models (BIM)

Net-Zero Energy Building Technologies and Strategies

Goal 2: Develop net-zero energy building technologies and strategies

Focus Area a. Develop building envelope materials, components, systems, and construction techniques to minimize building energy loads

Focus Area b. Develop ultra energy-efficient components and subsystems that minimize energy and satisfy building needs

Focus Area c. Develop supply-side technologies that, when coupled with energy efficiency, can achieve net-zero energy buildings and communities



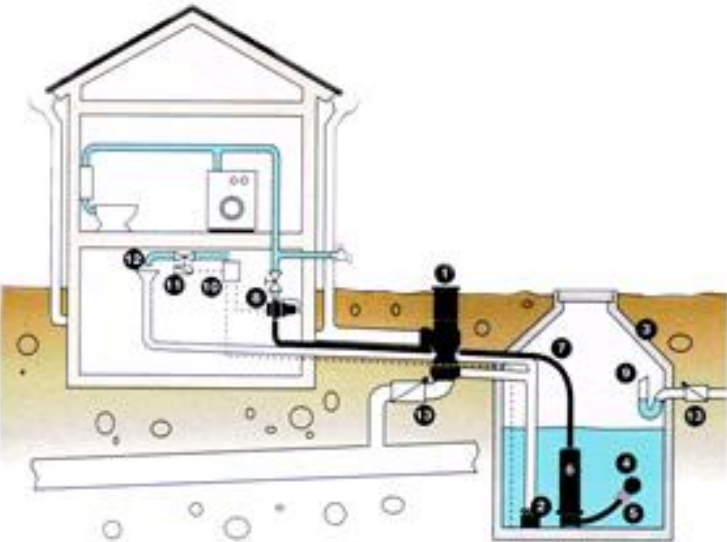
Water Use and Rainwater Retention

Goal 3: Develop the scientific and technical bases for significant reductions in water use and improved rainwater retention

Focus Area a. Reduce water use through more efficient water-saving appliances, fixtures, and water systems

Focus Area b. Develop analyses and technologies to overcome environmental, health, and technical barriers to widespread water recycling and increased rainwater harvesting

Focus Area c. Develop low-impact development practices to significantly reduce stormwater runoff



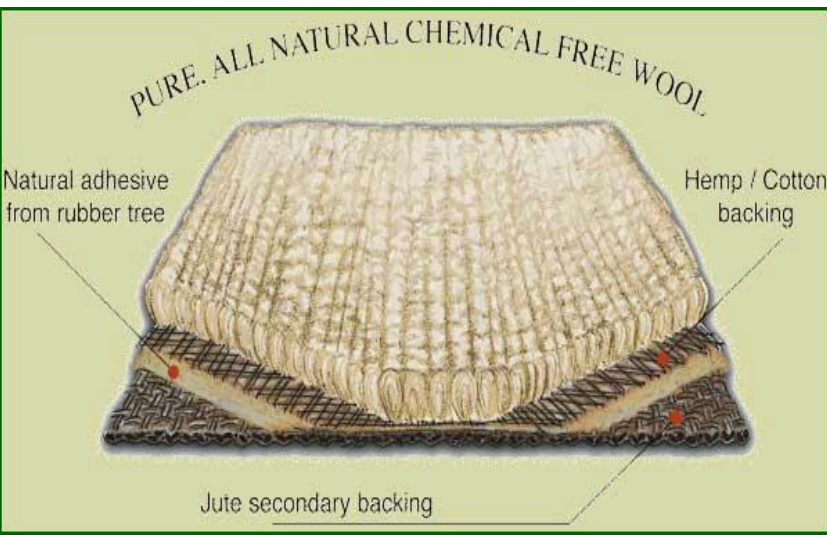
Material Utilization, Waste, and Life Cycle Environmental Impacts

Goal 4: Develop processes, protocols, and products for building materials that minimize resource utilization, waste, and life cycle environmental impacts

Focus Area a. Develop processes that minimize waste generation from building construction, renovation, and demolition

Focus Area b. Expand life cycle inventory data and perform life cycle assessments to identify the full environmental and public health impacts of product and material choices

Focus Area c. Develop new materials and products with minimal environmental and public health impacts over their life cycles



06/28/2010

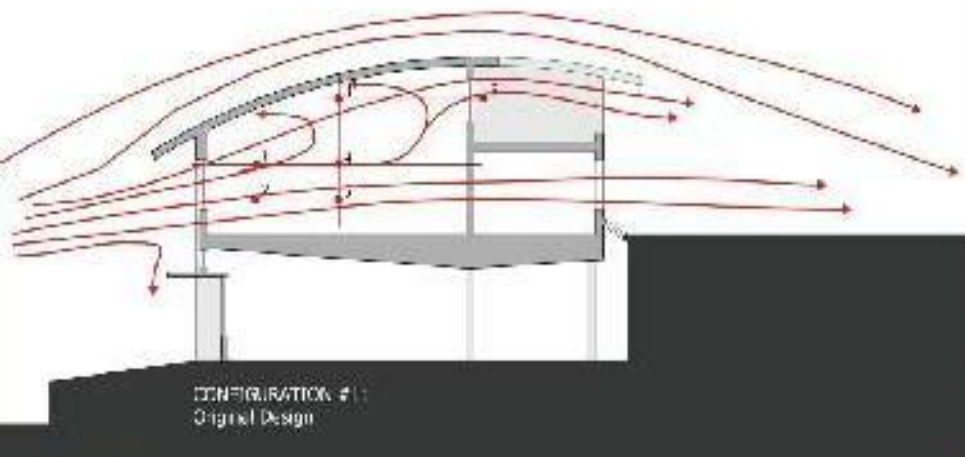


Occupant Health and Performance

Goal 5: Develop the knowledge and associated energy efficiency technologies and practices needed to promote occupant health, comfort, and productivity

Focus Area a. Develop technologies to improve indoor environmental quality and reduce building energy consumption

Focus Area b. Develop the knowledge necessary to support scientifically sound and building-specific standards and codes that address the health and comfort of building occupants



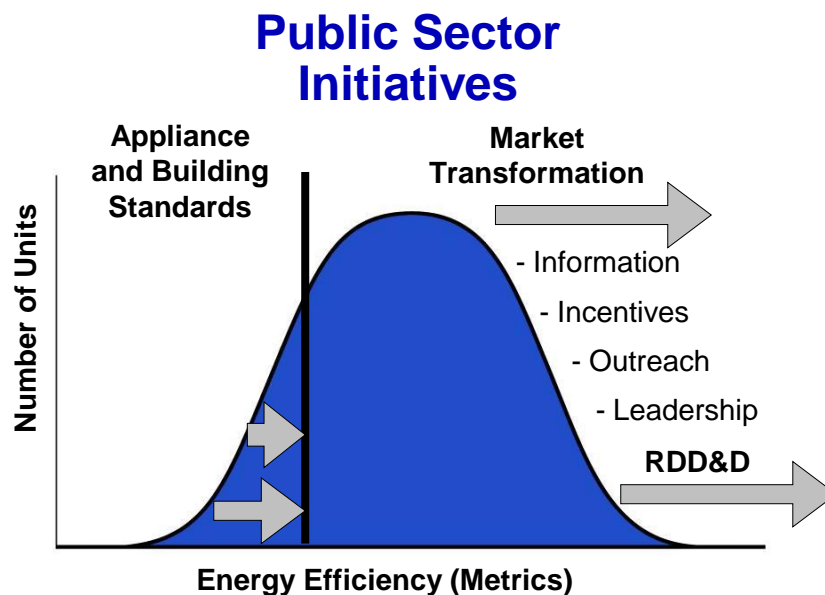
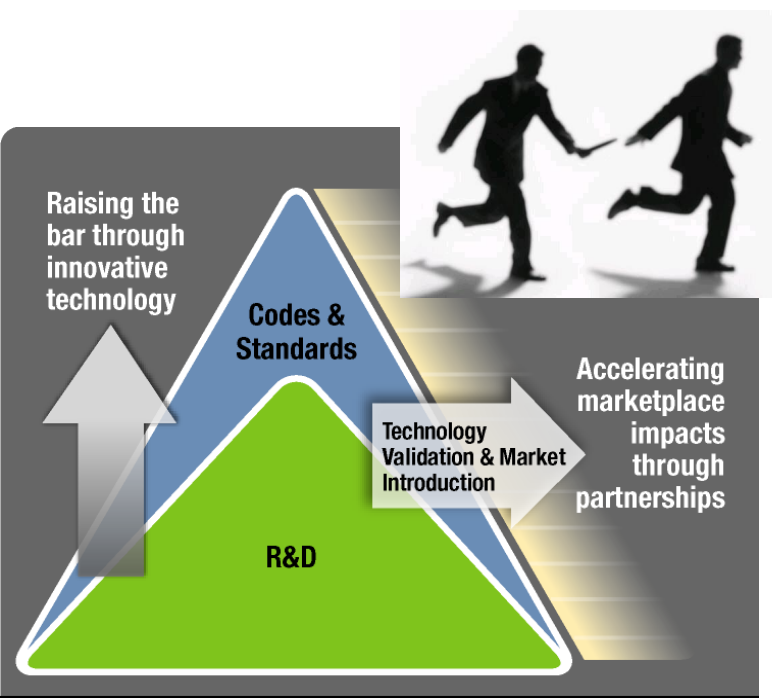
Overcoming Barriers to Implementation

Goal 6: Enable technology transfer for net-zero energy high-performance green buildings

Focus Area a. Develop high-performance building design tools and guidance for urban planners, architects, engineers, contractors, and owner/operators

Focus Area b. Develop tools and guides that enable the use of modern, adaptive performance-based building codes

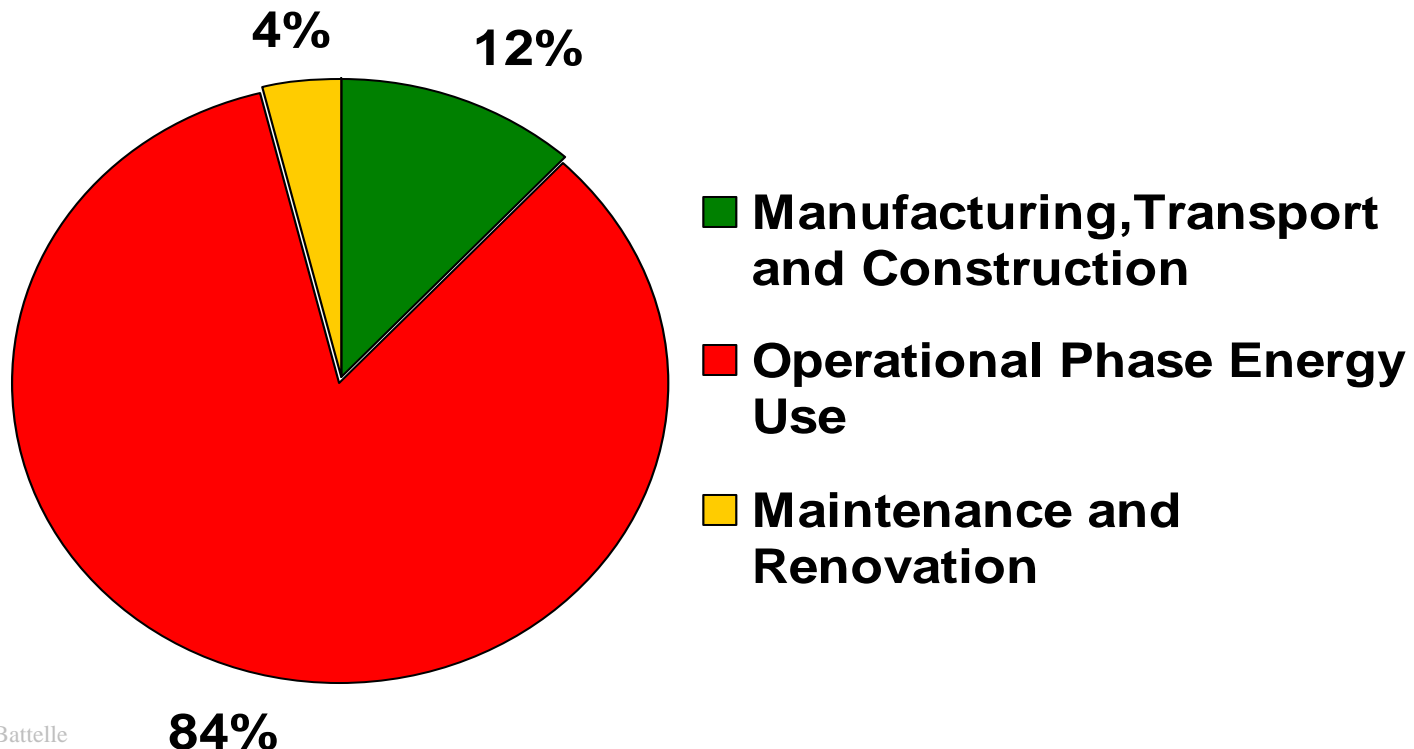
Focus Area c. Research and develop effective incentives for adopting and using innovative technologies and practices



DOE Focus is on Operational Phase Energy Use

- Minimize loads, satisfy remaining loads at ultra-high efficiency, supply-side technologies to achieve zero-energy

Building Life Cycle Energy Use



'Cool Colored' Roof and Wall Exteriors

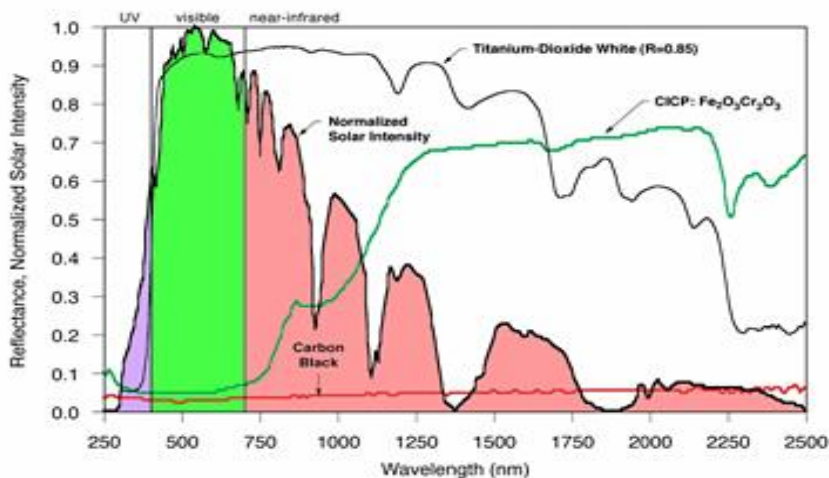
Flat Roofs → White

Reduce "Bake Temp"
→ Less Cooling



Walls & Sloped Roofs → "Cool" Colors

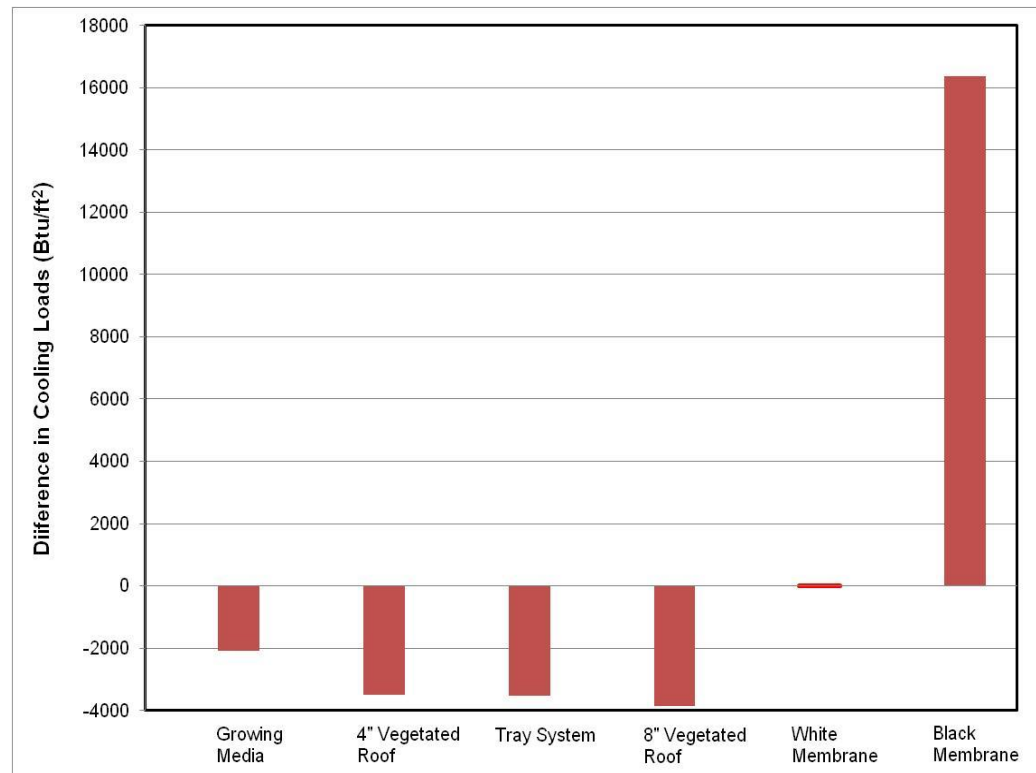
- Reflect solar, reduce cooling
- White is best
 - 'Dirty white' not appealing
- 'Cool colors' next best
 - Infrared reflective pigments
- 'Bake temp' 30 – 40°F lower
 - For cooling dominated climates
- Available for most roofing
 - Concrete or clay tile, painted metal, stone coated metal, asphalt shingle
- Available in wall paints
- New & retrofit
- www.coolroofs.org/



Vegetated Roofs Save Energy



Comparison of Cooling Loads (Heat Gain) Relative to White & Black Membranes

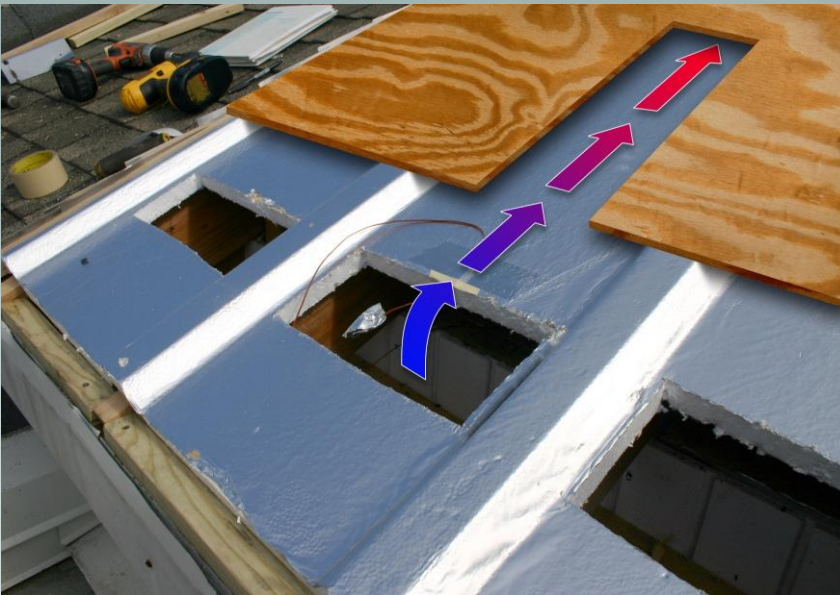


Naturally Ventilated Sloped Roofs

Above Roof Deck Natural Ventilation



Below Roof Deck Natural Ventilation



- Soffit-to-ridge natural ventilation
- For sloped roofs in cooling dominated climates
- Can roof-over existing roofs
- Energy savings benefit depends on the roof system and its characteristics
 - Greatest benefit: poorly insulated cathedral ceiling
 - Least benefit: heavily insulated attic with radiant barriers
- Benefits of roof and attic options are not additive
 - White? Cool? Vegetated? Ventilated? Insulated?
 - Need calculator to sort it out

Roof Savings Calculator: Credible Information for the Industry & Building Owners via Web

Q: What is the cost/benefit for my climate/application?

White Roof?



Cool Colored Roof?



Insulation Levels, Etc.?

Residential Roof Savings Calculator (RSC)

Go to: [Advanced Mode](#)

Building

1. Closest location (similar weather):
Select location:

2. Building Type:
Residential

3. Conditioned floor area (ft²):
2025

4. Number of floors:
1

5. Year of construction:
post-1990

Heating/Cooling

6. Heating equipment:
Electric heat pump
Natural gas furnace
Oil furnace
P1. Electricity price (cents per kWh): 11.65
P2. Natural gas price (dollars per 1000 ft³): 11.65

7. Heating system efficiency (AFUE):
High-efficiency (90%)
Mid-efficiency (83%)
Low-efficiency (70%)
Custom

8. Cooling system efficiency (SEER):
High-efficiency (15)
Mid-efficiency (13)
Low-efficiency (10)
Custom

Roof 1 - Existing Roof

9. Roof type:
Tile
Metal
Asphalt shingle

10. Solar reflectance (aged 3 yrs):
60%
50%
40%
30%
20%
10%

11. Thermal emittance (aged 3 yrs):
Acrylic Al-Zn coated steel (15%)
Bare Al-Zn coated steel (20%)
Metallic field-applied coating (50%)
Painted steel (85%)
Other materials (90%)

12. Above-sheathing ventilation:
Yes
No

13. Pitch (rise:run):
High (slope > 8:12)
Medium (2:12 < slope ≤ 8:12)
Low (slope ≤ 2:12)

14. Radiant barrier present:

15. Attic insulation (R-value):
R-50
R-38
R-30
R-22
R-19
R-15
R-11
R-5
R-3
None

16. Duct location:
Conditioned space
Attic

17. Duct leakage:
Inspected (4%)
Uninspected (14%)

Roof 2 - Cool Roof Comparison

18. Roof type:
Tile
Metal
Asphalt shingle

19. Solar reflectance (aged 3 yrs):
60%
50%
40%
30%
20%
10%

20. Thermal emittance (aged 3 yrs):
Acrylic Al-Zn coated steel (15%)
Bare Al-Zn coated steel (20%)
Metallic field-applied coating (50%)
Painted steel (85%)
Other materials (90%)

21. Above-sheathing ventilation:
Yes
No

22. Pitch (rise:run):
High (slope > 8:12)
Medium (2:12 < slope ≤ 8:12)
Low (slope ≤ 2:12)

23. Radiant barrier present:

24. Attic insulation (R-value):
R-50
R-38
R-30
R-22
R-19
R-15
R-11
R-5
R-3
None

25. Duct location:
Conditioned space
Attic

26. Duct leakage:
Inspected (4%)
Uninspected (14%)

Simulation Results

\$/yr

Energy Savings: 1300 kWh, 1300 kWh, 0.25 kWh

Monthly Savings: 108, 108, 0.21

Annual Savings: 1300 kWh, 1300 kWh, 0.25 kWh

Monthly Savings: 108, 108, 0.21

Annual Savings: 1300 kWh, 1300 kWh, 0.25 kWh

AtticSim

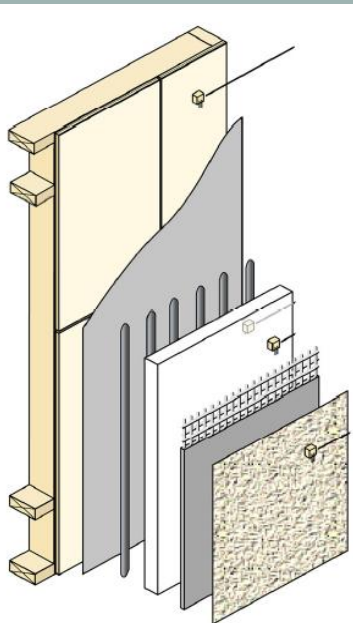
DOE-2

Calculate

Exterior Insulation Finishing Systems (EIFS)

- EIFs imported into the US from Germany in early 70s because of their potential energy efficiency benefits
- Major players: BASF, Dryvit Systems, Parex USA, Sto Corporation
- 1/3 of non-residential wall claddings (~300 million ft² per year)
- New self-drying designs (moisture durability no longer an issue)

- New & retrofit
- Aesthetic, airtight, high-R
- Eliminates framing thermal short circuits
- <http://www.eima.com/>



EIFS Industry Members Association (EIMA)

'Energy Storage' Envelope Systems

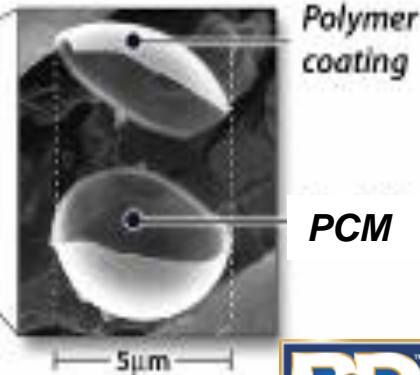
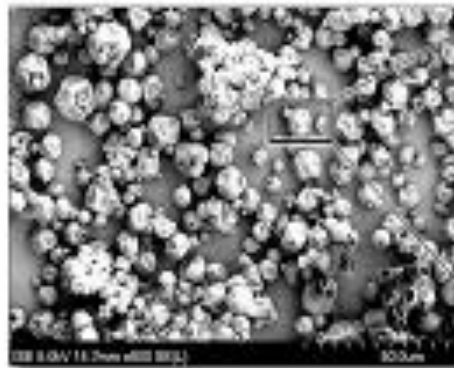
PCM-enhanced blown cellulose



Installation Approach
Remains the Same



- Cellulose with new phase change material (PCM) “ingredient”
- Cellulose (20% by weight PCM)
 - 12 in. insulation = 4 in. concrete
 - Takes away temperature difference to drive heat transfer
- 1st whole-building demo underway
- New & retrofit
- PCM micro-capsules by Microtek Labs (www.microtekllabs.com)
- PCM Cellulose by Advanced Fiber Tech (www.advancedfiber.com)



Phase Change Material (PCM) microcapsules
for fibrous insulation



HVAC, Water Heating, Working Fluids R&D

Ripple effects of GE's Heat Pump Water Heater Cooperative Research and Development Agreement (CRADA)

A.O. Smith's HPWH



Rheem's HPWH



GE's HPWH



Encouraged by this success,
additional CRADAs include:

- HVAC
- Rooftop Units (RTUs)
- Water Heating
- Low-GWP refrigerants
- Different Manufacturers

Over time, effects are amplified

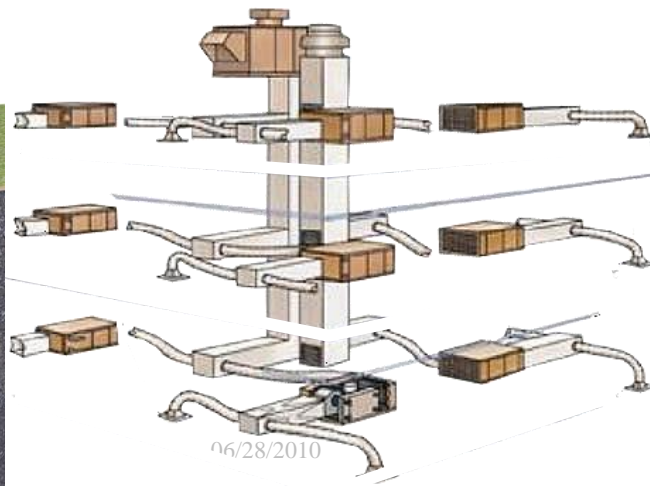
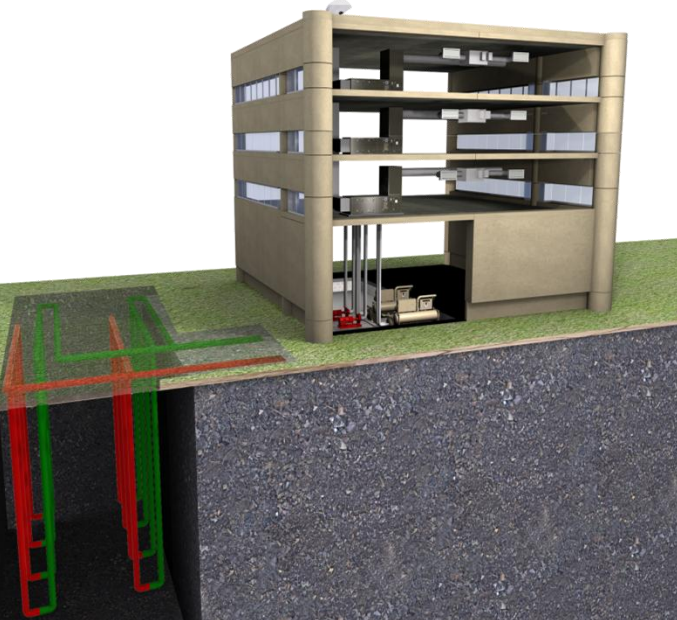
Challengers appear, set off by a single CRADA

Ground-Source Heat Pump Value is Rising

Heating, Cooling, Water Heating
& Extra Dehumidification Required:
Integrated Heat Pump

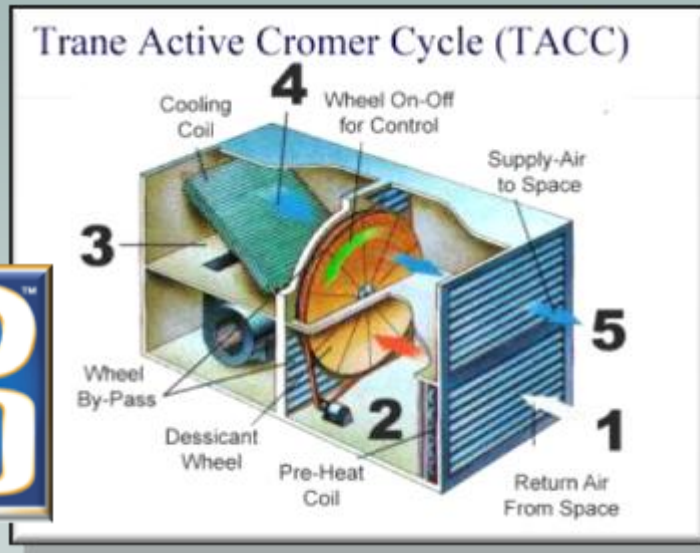


- Variable speed and 'integrated' heat pumps emerging
- Hybrid systems
- 1-pipe systems
- Financing schemes where serving utilities or 3rd parties build, own and maintain loops
 - Provide access for a monthly fee



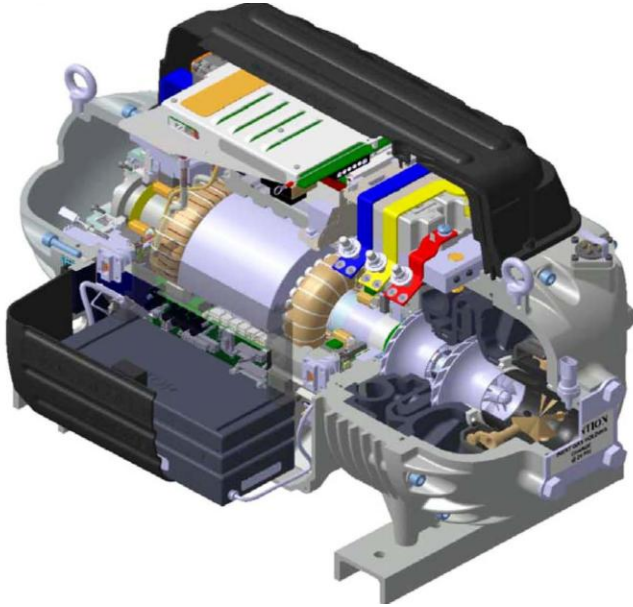
Rooftop Units Available With Greater Capacity for Moisture Removal (Latent Cooling)

Trane CDQ (Cool, Dry, Quiet)TM

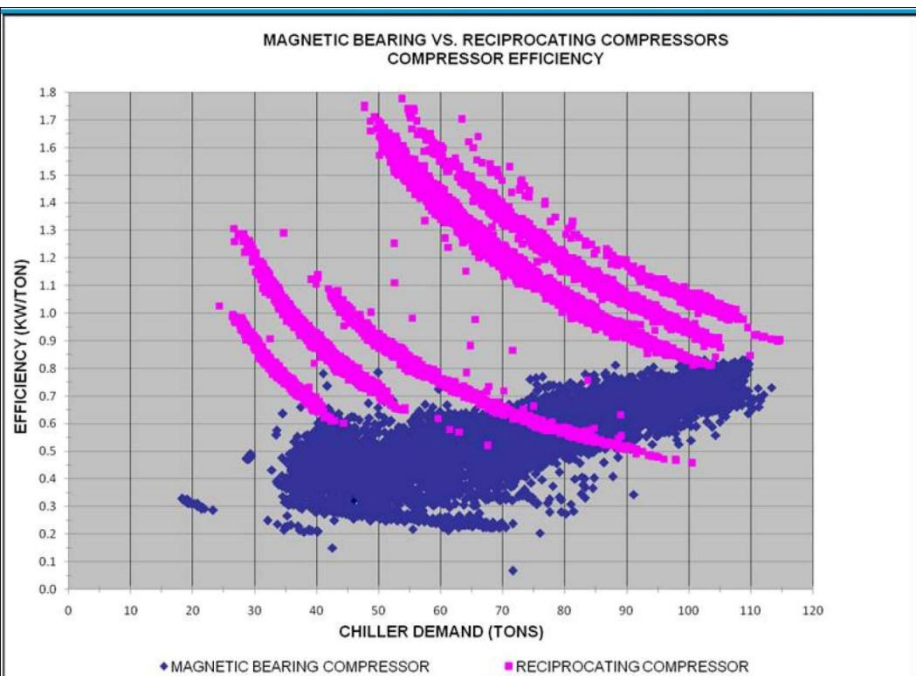


- Cascaded vapor compression and desiccant cycles
- Uses condenser waste heat to regenerate the desiccant
- Improves latent capacity (lowers sensible heat ratio - SHR) without reheat
- Knocks the moisture out of outdoor make-up air in humid climate applications
- Can pre-condition make-up air for conventional systems
- www.trane.com/commercial/dna/view.aspx?i=1070

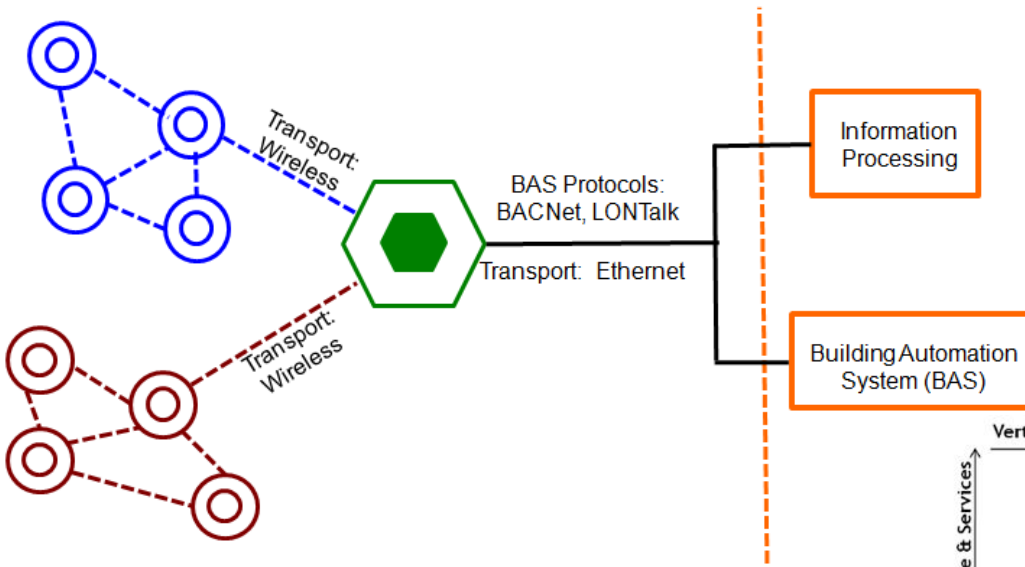
Oil Free Magnetic Bearing Centrifugal Chillers



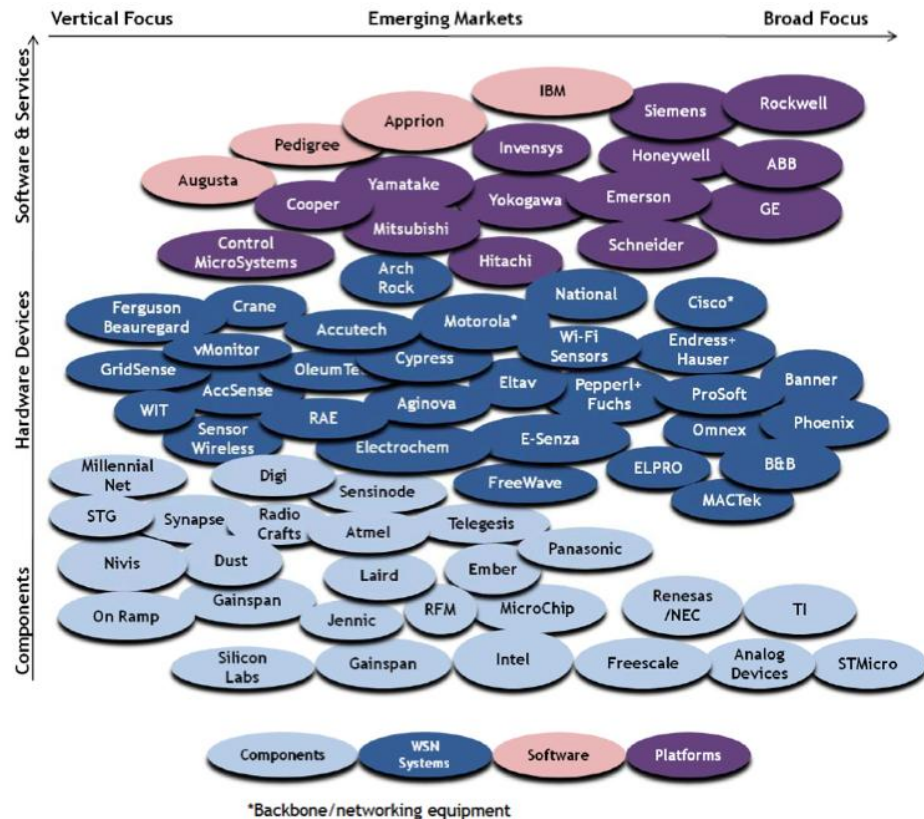
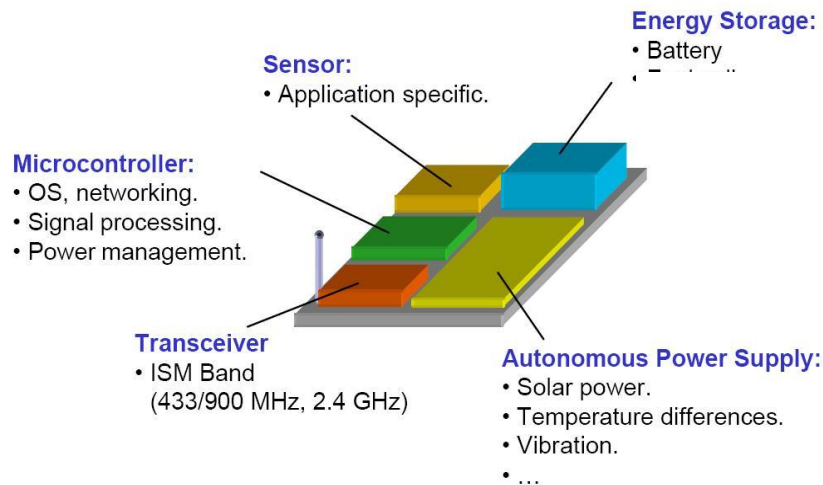
- 1994 Turbocor established
- 2001 first production unit
- 2004 Danfoss-Turbocor joint venture
- Today Danfoss-Turbocor compressors are used by several leading chiller manufacturers in the U.S., Europe, and Asia
- Excellent evaluations by the Navy Technology Validation (Techval) Program



Low-Cost Wireless Sensor Systems Emerging



- **Retro-commissioning, establish BAS, extend reach of existing BAS**
- **Actionable information on smart phone applications**



Buildings R&D Agenda—Big Job—Multi-Agency

- **Most of my examples were DOE/ORNL-centric**
 - Other DOE labs with significant buildings EE programs:
 - Lawrence Berkeley National Lab (LBNL), National Renewable National Lab (NREL), and Pacific Northwest National Lab (PNNL)
- **NIST Engineering Laboratory**
 - Buildings measurement science and technology R&D
- **Environmental Protection Agency**
 - Energy Star; water use reduction, recycling, rainwater harvesting
- **Department of Defense**
 - Environmental Security Technology Certification Program (ESTCP)
 - Navy Technology Validation (Techval) Program
- **General Services Administration**
 - Office of Federal High-Performance Green Buildings
- **Every federal agency – lead by example**



For more information on Building Technologies at ORNL, please contact:

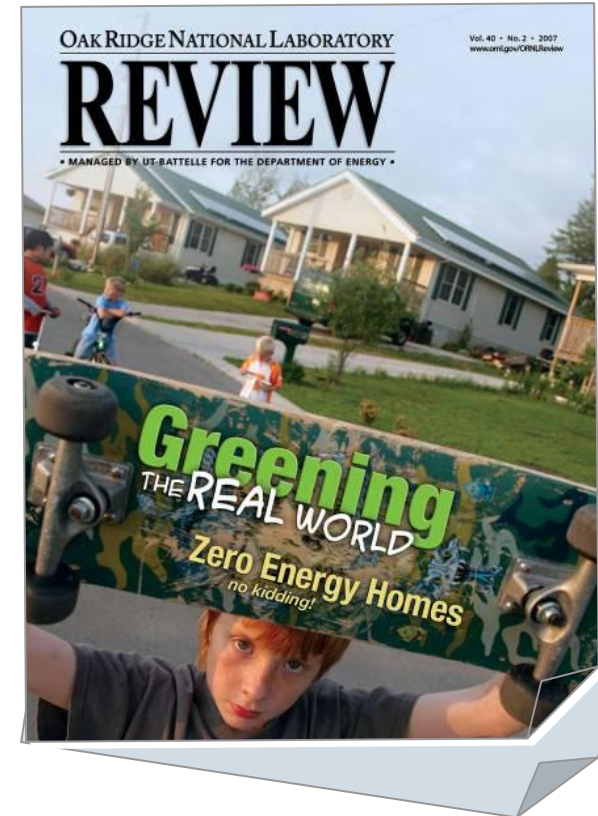
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<http://www.ornl.gov/sci/ees/etsd/btric/>

<http://www.zebralliance.com/>



<http://www.ornl.gov/info/ornlreview/>